

Influence of Substrate on the Excess Electrical Noise in the Normal State of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ Thin Films.

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Abstract

We present our studies of the low frequency excess electrical noise in $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ thin films in the normal state. We have studied films with varying microstructure deposited on different substrates. The frequency dependence and bias current dependence of the noise power spectral density agree with the behavior expected for noise due to conductance fluctuations. Comparison between films on different substrates shows that the presence of defects such as grain boundaries in the film correlate with significantly enhanced noise levels. The noise levels in our good quality epitaxial films are several orders of magnitude lower than the anomalously large noise magnitudes reported for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ in most of the earlier studies.

Over the past few years, several studies [1-4] have pointed out that the high T_c superconducting (HTS) materials exhibit anomalously large magnitudes of excess electrical noise both in the normal state and in the transition region. The enhanced noise levels have been observed in ceramic materials, single crystals and in thin films. However, there has been no consensus on the intrinsic magnitude of the noise since the noise levels have often been found to be highly sample dependent. Some of the more recent studies on epitaxial thin films have reported evidence of the influence of the substrate lattice match [5] and the oxygen content [6] on the magnitude of the excess noise in the normal state.

The above scenario suggests that systematic studies are needed to characterize the excess noise levels in the HTS systems. Information on the correlation of microstructure and the noise characteristics is important for optimizing the material microstructure for technological applications. To this end, we have studied the behavior of the excess electrical noise in the normal state of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) thin films on different substrates.

We have studied YBCO films on three different substrates : (i) (100) oriented LaAlO_3 (ii) R- plane Sapphire with a buffer layer of (100) CeO_2 (iii) polycrystalline Yttria Stabilized Zirconia (Poly YSZ) . (100) LaAlO_3 is well lattice-matched with YBCO (mismatch $\sim 1.8\%$) and its thermal expansion coefficient ($\sim 1 \times 10^{-5} / \text{K}$) is close to that of YBCO ($1.2 \times 10^{-5} / \text{K}$) . The lattice mismatch of YBCO with the CeO_2 buffer on the R-plane Sapphire is $\sim 0.8\%$; however there is significant mismatch between the thermal expansion coefficients of YBCO and Sapphire ($5 \times 10^{-5} / \text{K}$) which is expected to result in tensile stresses in the film. In the case of YBCO films on polycrystalline YSZ, there is no in-plane alignment due to the polycrystalline nature of the substrates. Thermal expansion mismatch is not of much relevance in this case since the polycrystalline nature of the film allows the strains to be relieved through structural defects such as grain boundaries.

The thin film samples were prepared by pulsed laser deposition (PLD)

under standard preparation conditions for YBCO films [7]. Structural analysis of the films was carried out using a four circle X-Ray diffractometer. Θ - 2Θ scans indicate that the films are single phase and c-axis oriented. Rocking angle analysis of the (005) peak (to evaluate the degree of texturing) indicate FWHM $\sim 0.3^\circ$ for the films on (100) LaAlO_3 . The films on R-plane Sapphire and those on poly YSZ have FWHM $\sim 0.5^\circ$ and $\sim 0.6^\circ$ respectively indicating larger c-axis misalignments compared to the films on (100) LaAlO_3 . Φ scan analysis of the (103) peaks of YBCO presented in Fig.(1) show that for the films on (100) LaAlO_3 and R-plane sapphire the a,b axes of the film are aligned with the a,b axes of the LaAlO_3 and the CeO_2 respectively. In contrast, the Φ scans for the films on poly YSZ show no peaks above the broad background indicating no in-plane alignment as expected.

The films (2000 Å thick) on the different substrates were characterized for their structural and electrical transport characteristics. Micro bridges 20 - 80 μm wide and 500 -800 μm long were patterned by photolithography. All the films had $T_c \sim 90$ K. The critical current density (J_c) at 77K was greater than 10^6 A / cm^2 for the films on (100) LaAlO_3 and R-plane sapphire and $\sim 10^5$ A / cm^2 for the films on poly YSZ. The reduction in the J_c in the latter case has been established to be due to the weak link effects associated with the grain- boundaries [8].

To measure the low frequency noise, a DC bias current from a battery operated current source was passed through the sample with a large (~ 1000 times the sample resistance) ballast resistance in series. The sample voltage was capacitively filtered and transformer-coupled to a low noise amplifier and fed to a dynamic signal analyzer for Fourier transform analysis. The input noise floor level of the measurement system was ~ 8 nV / Hz. The measured noise level in the superconducting state of the samples (when biased below the critical currents) is below this background which we infer as the upper limit to possible contributions due to noise associated with contact resistances. In order to identify possible contributions due to current source, thermal drift etc. we measure the noise in low noise metal film resistors under identical conditions as our samples. We find no

noise above the background in such samples which rules out contributions from these extrinsic sources above the background level.

We observe frequency dependent excess noise in all the films down to 90 K. The spectral density of the excess noise voltage ($S_V^{1/2}$) is linear in the bias current. The frequency dependence in the 1-100 Hz range shows a $1/f^\alpha$ dependence of the noise power spectral density, α being in the range of 1-1.3 characteristic of the noise associated with the conductance fluctuations similar to that observed in conventional metals. To parametrize the observed noise, we have used Hooge's empirical relation for conductance fluctuations given by

$$S_V(f) / V_{DC}^2 = \gamma / (n_c * vol * f^\alpha) \dots\dots\dots(1)$$

where V_{DC} is the DC voltage across the sample, n_c is the volume density of charge carriers in the sample, f is the frequency and γ represents the strength of the noise sources. In conventional metals the values of γ are in the range $\sim 10^{-3} - 10^{-4}$ [9]. We would like to emphasize here that Hooge's formula is empirical and does not imply any universal characteristics of the noise spectrum or its origin. We use it here only to present the data in a normalized way to facilitate comparison of the noise magnitudes in the different samples.

In Fig. (2) we show S_V / V_{DC}^2 as a function of temperature. The frequency span of these measurements cover the range 1-100 Hz. The data presented is for $f=11$ Hz with a bias current density $\sim 3 \times 10^4$ A / cm². In the case of YBCO / LaAlO₃ and YBCO/ Poly YSZ S_V / V_{DC}^2 decreases with decreasing temperature. This temperature dependence is similar to that observed for YBCO on (100) MgO [5] . However, the data for YBCO / Sapphire shows a qualitatively different temperature dependence where S_V / V_{DC}^2 increases with decreasing temperature. From the above data, $\gamma(T)$ cannot be determined unambiguously since the charge carrier density $n_c(T)$ is not a well determined quantity for YBCO. However, using γ / n_c we can compare the relative strength of the noise sources and the temperature dependences. To facilitate such a comparison, in Fig.3 we replot the data on a logarithmic scale showing $\gamma/n_c = S_V * f^*$

Volume / V_{DC}^2) as a function of temperature for the three cases. It is clear that γ / n_c for the polycrystalline YBCO films is nearly 5 orders of magnitude larger than that of the epitaxial films on (100) $LaAlO_3$ while the noise level of films on CeO_2 buffered Sapphire are intermediate. From the above data we have evaluated γ at room temperature, using $n_c \sim 5.7 \times 10^{21} / \text{cm}^3$ [6]. In Table 1 we present the value of γ calculated from our data along with the relevant sample characteristics. The value of γ (≈ 0.05) for YBCO / $LaAlO_3$ is nearly an order of magnitude larger than the γ ($= 5 \times 10^{-3}$) reported for YBCO / $SrTiO_3$ [5]. The higher noise level in YBCO / $LaAlO_3$ may be related to the presence of substrate twin boundaries which propagate into the film. It is important to note that the γ values obtained for our YBCO / $LaAlO_3$ films (and those for the YBCO / $SrTiO_3$ films in ref.5) are much lower than the γ values ($10^4 - 10^5$) reported earlier for bulk ceramics, single crystals as well as thin films of YBCO [1,2]. We obtain $\gamma \sim 1.0$ for YBCO films on Sapphire while $\gamma \sim 2 \times 10^4$ for the films on polycrystalline YSZ. The enhancement of γ by 5 orders of magnitude in the polycrystalline films compared to the nearly single crystalline films on (100) $LaAlO_3$ clearly attests to the contribution of grain boundaries to the conductance fluctuations. Intergrain transport involving tunneling or hopping conduction has been suggested to be a source of conductance fluctuations associated with the trapping or detrapping of carriers by semiconducting or insulating regions at grain boundaries [10].

The temperature dependence of S_V / V^2 may be understood in terms of the thermal activation of the defect fluctuations. In the framework of the Dutta-Horn model [9], the temperature dependence relates to the energy distribution $D(E)$ of the fluctuating states. The temperature dependence seen in YBCO / $SrTiO_3$ has been shown to be indicative of a peak in $D(E)$ centered around 1 eV while in the case of YBCO / MgO this peak is seen to be considerably broadened [5]. The temperature dependence seen in our experiments for YBCO / $LaAlO_3$ and YBCO / Poly YSZ suggests a relatively broad spectrum of activation energies as seen in the case of YBCO / MgO . At present we are not clear about the origin of

the apparent peak at $\sim 250\text{K}$ in the polycrystalline sample which (if intrinsic) may be associated with low energy modes of fluctuations. The temperature dependence observed in YBCO/ Sapphire shows a striking difference, the noise levels increasing with decreasing temperature. In the light of the above analysis, this would suggest a broad peak in the energy distribution centered at a much lower temperature close to 100 K , implying reduced activation energy of such fluctuations. It may be noted here that though the films on Sapphire have good lattice match with the CeO_2 buffer layer, the significant mismatch in the thermal expansion coefficients between the substrate and the film is expected to result in tensile stresses in the film. The presence of such stresses could lower the activation energies causing the peak to shift to lower temperatures. It is of interest to investigate the influence of this anomaly on the noise in the transition range since Sapphire is a preferred substrate for bolometers and related detector applications on account of its thermal properties. We are currently pursuing this study.

It is clear from the above results that the microstructure plays an important role in determining the excess noise levels in the normal state. Grain-boundaries when present could be a dominant source of excess noise as indicated by the enhanced noise levels in the films on polycrystalline YSZ. Overall, the noise levels in our epitaxial films with good superconducting properties are several orders of magnitude lower than the values reported in some of the earlier studies in single crystals and thin films of YBCO. Based on these results, we suggest that the anomalously large and often sample dependent low frequency noise often observed in the normal state of HTS materials may have a significant contribution from microstructural defects such as grain boundaries. In the case of thin films, the stresses in the film associated with lattice mismatch or thermal expansion may also lead to enhanced noise levels.

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References

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Figure Captions

Fig.1

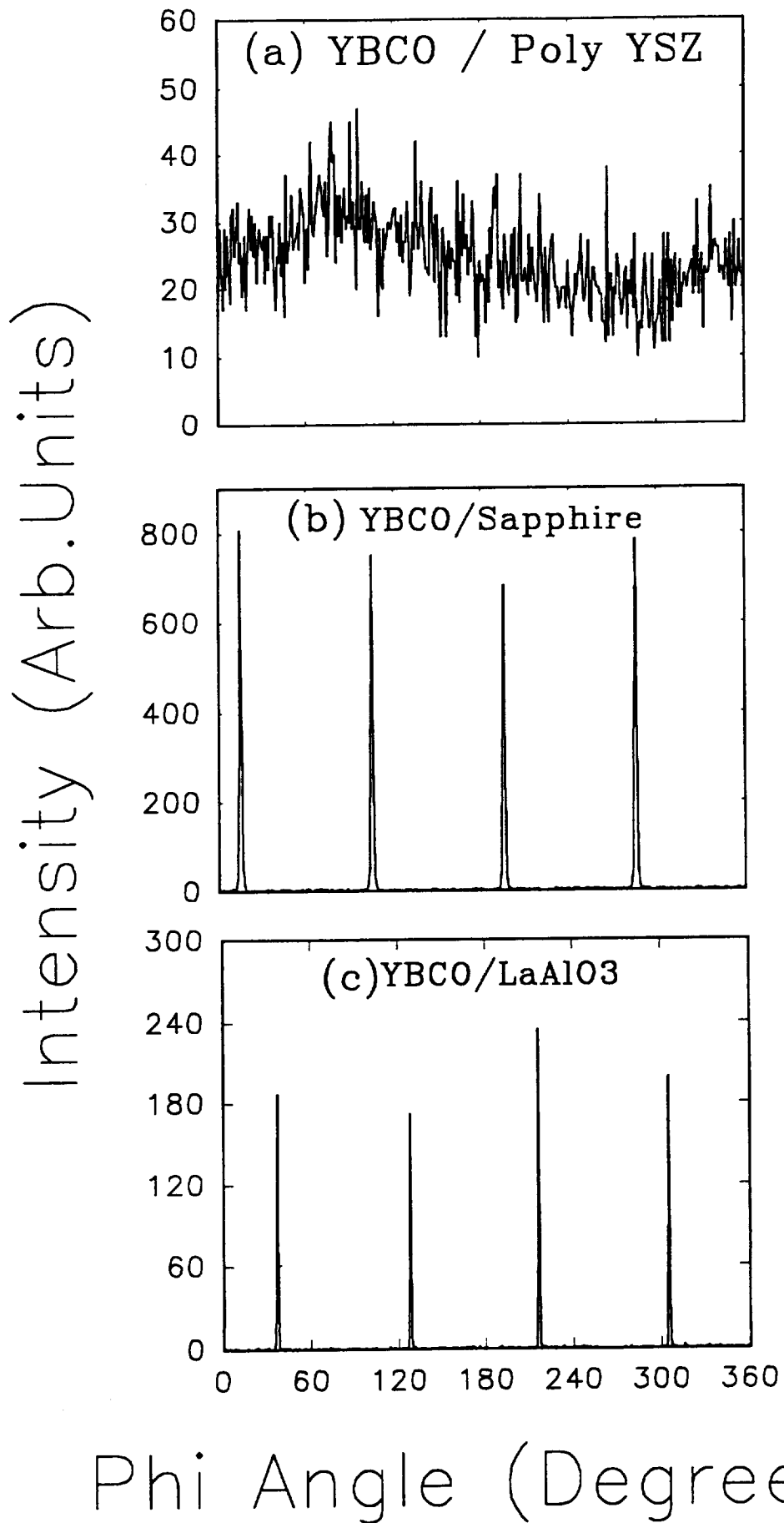
Φ scans of the (103) peak of YBCO : (a) YBCO/ Poly YSZ (b) YBCO / CeO₂ / Sapphire (c) YBCO / (100) LaAlO₃

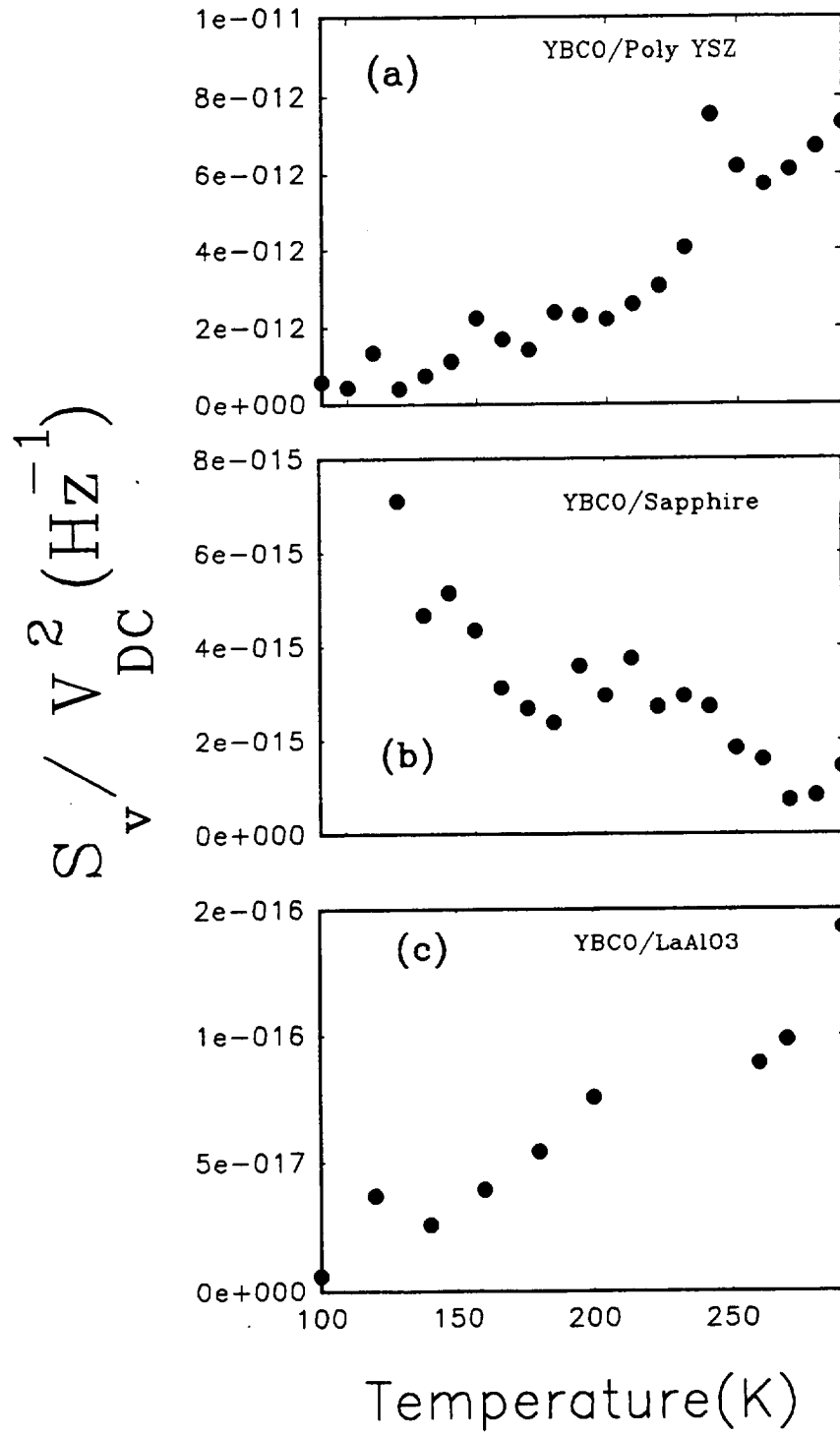
Fig.2

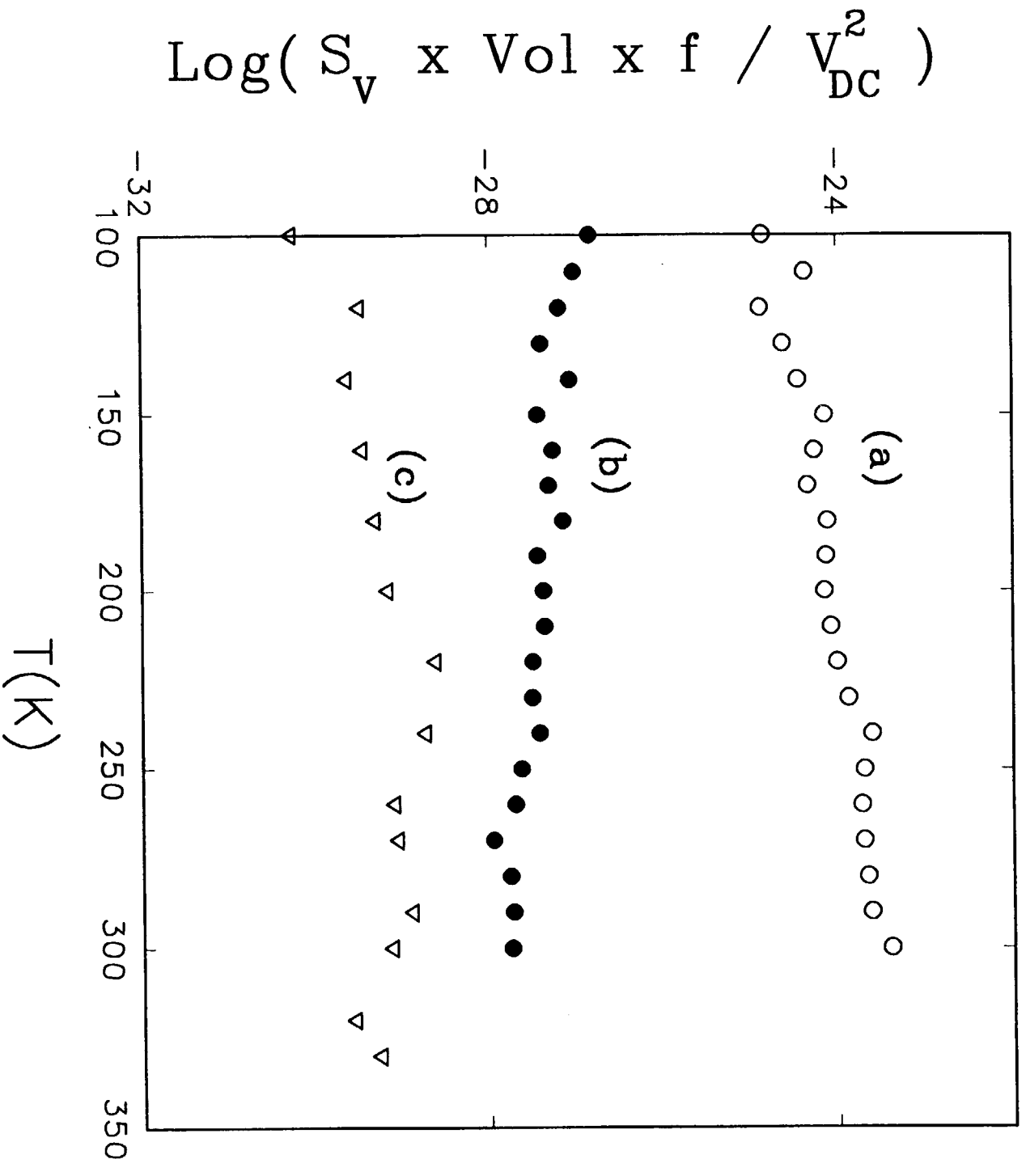
Normalized noise power spectral density S_V / V_{DC}^2 as a function of temperature in the normal state (a) YBCO/ Poly YSZ (b) YBCO / CeO₂ / Sapphire (c) YBCO / (100) LaAlO₃

Fig.3

Comparison of the normalized noise power spectral density $S_V * f * \text{volume} / V_{DC}^2$ for YBCO films ; (a) YBCO/ Poly YSZ (b) YBCO / CeO₂ / Sapphire (c) YBCO / (100) LaAlO₃







7:45 A.M. F6.3

FIELD DEPENDENCE OF PROTON-IRRADIATION INDUCED CRITICAL CURRENT ENHANCEMENT IN BULK YBCO MATERIALS. R. Gerbaldi, G. Ghigo, L. Gozzelino, E. Merzetti, B. Minetti, Politecnico di Torino, Department of Physics, Torino, Italy; and R. Cerebini, L.N.F.N., Padova, Italy.

10:00 A.M. F6.4

CHANGES IN OXYGEN SUBLATTICE OF $\text{YBa}_2\text{Cu}_3\text{O}_x$ CRYSTALS AFTER ^{60}Co GAMMA IRRADIATION IN SUPERCONDUCTING STATE. Elvira M. Ibragimova, Olga Yu. Polyak, Anatoly F. Nebasny, Eldar M. Gasanov, INP, Tashkent, Uzbekistan; Marquis A. Kirk, Argonne National Laboratory, Argonne, IL; John Giapantzas, University of Illinois at Urbana-Champaign, Department of Materials Research, Urbana, IL; A.J. Shamima Chowdhury, Chen Changkang and Michael L. Jenkins, University of Oxford, Department of Materials Research, Oxford, United Kingdom.

10:15 A.M. BREAK

10:45 A.M. *F6.5

FLUX PINNING AND DEFECTS IN MELT-PROCESSED RE123 (RE: Nd, Sm Eu) SUPERCONDUCTORS. Masato Murakami, Sang-In Yoo, Naomichi Sakai, Francesca Frangi and Takamitsu Higuchi, International Superconductivity Technology Center, Superconductivity Research Laboratory, Tokyo, Japan.

11:15 A.M. *F6.6

EFFECTS OF MECHANICALLY INDUCED DEFECTS AND SUBSEQUENT HEAT TREATMENT ON FLUX PINNING IN CERAMIC SUPERCONDUCTORS. M.J. Kramer, Ames Laboratory, Metallurgy and Ceramics Department, Ames, IA.

11:45 A.M. F6.7

PROBING THE LIMITS OF FLUX PINNING IN A HIGH FIELD LOW TEMPERATURE SUPERCONDUCTOR. E. Kadyrov, A. Gurevich, P. Lee and D. Larbalestier, University of Wisconsin-Madison, Superconductivity Center, Madison, WI.

SESSION F7: GRAIN BOUNDARIES

Y. Iwasa, K. Yamaguchi, and K. Kawasaki

1:30 P.M. F7.1

GRAIN BOUNDARIES IN YBCO FILMS: MICROSTRUCTURE TRANSPORT PROPERTIES AND CONTROLLED EPITAXY. K.L. Merkle and B.V. Vuchic, Argonne National Laboratory, Materials Science Division, Argonne, IL.

2:30 P.M. F7.2

GRAIN BOUNDARY STRUCTURE IN YBCO FILMS GROWN ON SrTiO_3 SUBSTRATES AND TRANSPORT PROPERTIES. J. F. Zangwill, University of Maryland, College Park, Maryland.

2:30 P.M. F7.3

MICROSTRUCTURES OF ARTIFICIALLY-INDUCED Σ GRAIN BOUNDARIES IN $\text{YBa}_2\text{Cu}_3\text{O}_x$ THIN FILMS GROWN ON SrTiO_3 BICRYSTAL SUBSTRATES AT DIFFERENT DEPOSITION RATES. X.F. Zhang, D.J. Miller, Argonne National Laboratory, Materials Science Division, Argonne, IL; and J. Talvacchio, Westinghouse Science and Technology Center, Pittsburgh, PA.

2:45 P.M. F7.4

THE ATOMIC ORIGINS OF THE CRITICAL CURRENT BEHAVIOR OF GRAIN BOUNDARIES IN $\text{YBa}_2\text{Cu}_3\text{O}_x$ THIN FILMS. N.D. Browning, University of Illinois at Chicago, Department of Physics, Chicago, IL; and S.J. Pennycook, Oak Ridge National Laboratory, Solid State Division, Oak Ridge, TN.

3:00 P.M. F7.5

MAPPING OXYGEN ACROSS GRAIN BOUNDARIES IN $\text{YBa}_2\text{Cu}_3\text{O}_x$ THIN FILMS USING PEELS. J.L. Lee, D. Chamberlain, R.A. Buhrman, Cornell University, Department of Materials Science and Engineering, Ithaca, NY; and J. Silcox, Cornell University, Department of Applied and Engineering Physics, Ithaca, NY.

3:15 P.M. BREAK

3:45 P.M. *F7.6

CURRENT-LIMITING EFFECTS OF GRAIN BOUNDARIES IN YBaCuO AND BiSrCaCuO SUPERCONDUCTORS. D.C. Larbalestier, University of Wisconsin, Applied Superconductivity Center, Madison, WI.

4:15 P.M. F7.7

MICROSTRUCTURE OF $\sim 10^\circ$ [001] TILT BOUNDARY IN THIN-FILM AND BULK-SCALE $\text{YBa}_2\text{Cu}_3\text{O}_x$ BICRYSTALS. I-Fei Tsu, S.E. Babcock, N.F. Heimg, D.C. Larbalestier, R.D. Redwing, J.N. Nordman, University of Wisconsin, Madison, WI; and D.L. Kaiser, National Institute of Standards and Technology, Gaithersburg, MD.

4:30 P.M. F7.8

TRANSPORT PROPERTIES OF SUPERCONDUCTING $\text{Ba}_2\text{Sr}_2\text{CaCu}_3\text{O}_{10}$ BICRYSTAL GRAIN BOUNDARIES. Qiang Li, Y.N. Tsai and M. Soenaga, Brookhaven National Laboratory, Department of Applied Science, Upton, NY.

4:45 P.M. F7.9

GRAIN BOUNDARY CHARACTER DISTRIBUTION ANALYSIS OF BULK PROCESSED $\text{YBa}_2\text{Cu}_3\text{O}_x$. J.Y. Wang, A.H. King, State University of New York, Department of Materials Science and Engineering, Stony Brook, NY; Y.-L. Wang, Y. Zhu and M. Soenaga, Brookhaven National Laboratory, Department of Applied Science, Upton, NY.

POSTER SESSIONS

Tuesday Evening, November 28
8:00 P.M.

America Ballroom (W)

SESSION F8: GRAIN BOUNDARIES

F8.1 ELECTRON MICROSCOPY OF $\text{YBa}_2\text{Cu}_3\text{O}_x$ GRAIN BOUNDARIES OBTAINED ON STRAIGHT AND WAVY STEP EDGES ON (001) LaAlO_3 SUBSTRATES. M. Gustafsson, E. Olsson, H.R. Yi, D. Winkler and T. Claeson, Chalmers University of Technology, Department of Physics, Göteborg, Sweden.

F8.2 MIXED ELECTROMAGNETIC COUPLING IN 3° TO 15° [001] TILT GRAIN BOUNDARIES IN $\text{YBa}_2\text{Cu}_3\text{O}_x$ BICRYSTAL FILMS ON SrTiO_3 . N.F. Heimg, University of Wisconsin, Applied Superconductivity Center and Department of Materials Science and Engineering, Madison, WI; R.D. Redwing, University of Wisconsin, Department of Physics, Madison, WI; J.E. Nordman, University of Wisconsin, Department of Electrical and Computer Engineering, Madison, WI; and D.C. Larbalestier, University of Wisconsin, Department of Materials Science and Engineering, Madison, WI.

F8.3 GROWTH, MICROSTRUCTURES AND PROPERTIES OF ENGINEERED GRAIN BOUNDARIES IN $\text{YBa}_2\text{Cu}_3\text{O}_x$ BULK MATERIALS. V.R. Todt, X.F. Zhang, and D.J. Miller, Argonne National Laboratory, Materials Science Division, Argonne, IL.

F8.4 ELECTROMAGNETIC AND MICROSTRUCTURAL STUDIES OF NATURAL-GROWN BULK-SCALE [001] TILT BICRYSTALS OF $\text{Bi}_2\text{Sr}_2\text{CaCu}_3\text{O}_{10}$. Jyh-Lih Wang, I-Fei Tsu, X.-Y. Chen, R.J. Kelley, S.E. Babcock, D.C. Larbalestier, University of Wisconsin, Madison, Applied Superconductivity Center, Madison, WI; and M.D. Vaudin, National Institute of Standards and Technology, Ceramics Division, Gaithersburg, MD.

F8.5 EXPERIMENTAL EVIDENCE FOR ELECTROMAGNETIC COUPLING INHOMOGENEITY ALONG THE GRAIN BOUNDARY PLANE IN HIGH-ANGLE MELT-GROWN $\text{YBa}_2\text{Cu}_3\text{O}_x$ BICRYSTALS. Michael B. Field, Argonne National Laboratory, Materials Science Division, Argonne, IL; and David C. Larbalestier, University of Wisconsin-Madison, Madison, WI; Apurva S. Parikh and Kamel Salama, University of Houston, Houston, TX.

F8.6 MAGNETO TRANSPORT STUDIES OF YBCO BI-CRYSTAL JUNCTIONS. C. Bonetto, N.E. Israeloff, R. Seed, C. Vittoria and C. Surya, Northeastern University, Department of Electrical and Computer Engineering, Boston, MA.

F8.7 COMPARATIVE STUDY OF UNDOPED AND Ag-DOPED $\text{YBa}_2\text{Cu}_3\text{O}_x$ THIN FILMS ON $<100>$ MgO SUBSTRATE. R.D. Vispute, North Carolina State University, Department of Materials Science and Engineering, Raleigh, NC; Ramit Bhandari, C.B. Lee, North Carolina A&T State University, Department of Electrical Engineering, Greensboro, NC; D. Kumar, K. Jagannathan and J. Narayan, North Carolina State University, Department of Materials Science and Engineering, Raleigh, NC.

F8.8 ELECTRICAL NOISE IN THE SUPERCONDUCTING TRANSITION RANGE OF $\text{YBa}_2\text{Cu}_3\text{O}_x$ THIN FILMS. M. Rajeswari, A. Goyal, A. Kidane, S. Lakeon, University of the District of Columbia, Department of Engineering and Technology, Washington, DC; E.A. Wood, T. Venkatesan, University of Maryland, Center for Superconductivity Research, Department of Physics, College Park, MD; K.S. Harshvardhan and Z. Shi, Neocera Inc., Beltsville, MD.

F8.9 TWIN AND BLOCK STRUCTURE OF THE $\text{YBa}_2\text{Cu}_3\text{O}_x$ THIN FILMS STUDIED BY THE X-RAY ANALYSIS. Alexander I. Ruban, Edward M. Rudenko, Nikolai D. Rud and Anatolii I. Usunov, Institute for Metal Physics, Kiev, Russia.

F8.10 DOMAIN STRUCTURE AND TWIN BOUNDARY MIGRATION IN HIGH TEMPERATURE SUPERCONDUCTING SINGLE CRYSTALS. R. Javarel, A. Thamizhavel, P. Murugakoothan, and C. Subramanian, Anna University, Crystal Growth Centre, Madram, India.

F8.11 TWINNING IN LARGE GRAINS OF $\text{YBa}_2\text{Cu}_3\text{O}_x$ AS AFFECTED BY Y_2BaCuO_4 ADDITION. Manoj Chopra, V.S. Boiko, Columbia University, Henry Krumb School of Mines, New York, NY; R.L. Meng, C.W. Chu, Texas Center of Superconducting Research, Houston, TX; and S.W. Chan, Columbia University, Henry Krumb School of Mines, New York, NY.